Claims

[c1] 1. A method for actuating a valve disposed in a cylinder head of an internal combustion engine by an electromechanical valve system having an armature operatively connected to the valve, a valve closing electromagnet capable of exhibiting an electromagnetic force for attracting the armature to open the valve, a valve opening spring for biasing the armature in a direction to open the valve, and a valve closing spring for biasing the armature in a direction to close the valve, comprising the steps of:

de-energizing the valve closing electromagnet when said valve is in a substantially fully closed position;

maintaining the valve closing electromagnet in said de-energized state for a predetermined time enabling the valve to oscillate by force of the valve opening spring and the valve closing spring; and

energizing the valve closing electromagnet after said predetermined time to close the valve.

[c2] 2. The method of claim 1, said predetermined time is based on oscillation characteristics of the valve when the valve closing electromagnet is de-energized.

[c3] 3. The method of claim 1 wherein said valve is one of an intake valve and an exhaust valve.

[c4] 4. The method of claim 1, wherein said predetermined time is approximately a valve period, said valve period is the time elapsed between de-energizing the valve closing electromagnet until the valve returns to a nearly closed position for a first time.

[c5] 5. The method of claim 1, wherein said predetermined time is substantially an integral number of valve periods, said valve period is the time elapsed between de-energizing the valve closing electromagnet until the valve returns to a nearly closed position.

[c6] 6. The method of claim 5, wherein said integral number is less than a predetermined number.

[c7] 7. The method of claim 2, wherein said valve period is based on the spring constant of the valve opening spring, the spring constant of the valve closing spring, a mass of the valve, and a mass of the armature, and damping coefficients of the valve opening spring, the valve closing spring, the armature, and the valve.

[c8] 8. The method of claim 6, wherein said predetermined number is the number of a first occurring oscillation of the armature at which a trajectory of the armature fails to attain a predetermined distance away from said fully closed position, said predetermined distance is a maximum distance that the armature may be away from the valve closing electromagnet while being capable of being attracted by the valve closing electromagnet.

[c9] 9. The method of claim 1, wherein said predetermined time is a time when the valve is closer to a fully closed position of the valve than a distance at which the valve closing electromagnet is capable of attracting the armature and causing the valve to close.

[c10] 10. An electromagnetic valve apparatus for actuating a valve disposed in a cylinder head of an internal combustion engine, the engine having at least one cylinder, comprising:
an armature operatively connected to the valve;
a valve closing electromagnet capable of exhibiting an electromagnetic force for attracting said armature to close the valve;
a valve opening spring coupled to said armature for biasing said armature in a direction to open the valve;
a valve closing spring coupled to said valve for biasing the valve to a closed position; and
an electronic control unit operably connected to said valve closing electromagnet de-energizes said valve closing electromagnet allowing the valve to oscillate by force of said valve opening spring and said valve closing spring and maintains said valve closing electromagnet in said de-energized state at least until the valve travels to a nearly open position and returns to a nearly closed position.

[c11] 11. The system of claim 10 further comprising a position sensor coupled to said armature providing an indication of a position of the valve with respect to the cylinder head, said position sensor is connected to said electronic control unit.

[c12] 12. The system of claim 11 wherein said electronic control unit energizes said valve closing electromagnet to cause the valve to close when said position sensor indicates that the valve is within a predetermined distance from said cylinder head.

[c13] 13. The system of claim 12 wherein said predetermined distance is a maximum

distance that said armature may be away from the valve closing electromagnet while being capable of being attracted by the valve closing electromagnet.

[c14] 14. The system of claim 10 wherein said electronic control unit energizes said valve closing electromagnet at a predetermined time after said valve closing electromagnet is de-energized to cause the valve to close.

[c15] 15. The system of claim 14, said predetermined time is based on dynamic characteristics of the valve and the electromagnetic valve apparatus.

[c16] 16. The system of claim 14 wherein the valve is an intake valve.

[c17] 17. The system of claim 16 wherein said predetermined time is determined so as to provide a desired quantity of air to one cylinder of the engine.

[c18] 18. The system of claim 17 further comprising a piston disposed in the cylinder which reciprocates within the cylinder, wherein a time of performing said de-energizing step which enables oscillation of the valve is based on the position of said piston in the cylinder.

[c19] 19. The system of claim 16, further comprising a throttle valve disposed in the intake duct of the engine, wherein a time of performing said de-energizing step which enables oscillation of the valve and a position of said throttle valve are determined to provide a desired quantity of air to one cylinder of the engine.

[c20] 20. The system of claim 10 wherein the valve is an exhaust valve.

[c21] 21. The system of claim 20 wherein the engine is a homogeneous charge compression ignition engine and an opening time and a closing time of the valve is based on a desired portion of exhaust gases to retain in one cylinder.

[c22] 22. A method for actuating an intake valve disposed in a cylinder head of an internal combustion engine by an electromagnetic valve apparatus
actuating the valve according to a second mode when a second set of engine operating conditions are detected, said second mode further comprises the steps of de-energizing the valve closing electromagnet to allow the valve to open, energizing the valve opening electromagnet in response to said de-energizing step to attract the armature to the valve opening electromagnet thereby causing the valve to open; de-

energizing the opening electromagnet after a second predetermined time has elapsed since the valve opening electromagnet has been energized; and energizing the valve closing electromagnet in response to said de-energizing step of the valve opening electromagnet to attract the armature to the valve closing electromagnet thereby causing the valve to close.

[c23] 23. The method of claim 22, wherein said first predetermined time is based on oscillation characteristics of the valve when the valve opening electromagnet is de-energized and the valve closing electromagnet is de-energized.

[c24] 24. The method of claim 22, wherein the valve is an intake valve, said first set of engine operating conditions are those indicating a lower flow rate of air through the valve, and said second set of engine operating conditions are those indicating a higher flow rate of air through the valve.

[c25] 25. The method of claim 22, further comprising the step of inducting air past the valve as it oscillates, when the valve is operated according to said first mode.

[c26] 26. The method of claim 22, said first set of operating conditions is indicated by a lower engine speed and a lower engine torque.

[c27] 27. A computer readable storage medium having stored data representing instructions executable by a computer to open a valve disposed in a cylinder of an internal combustion engine, the valve is actuated by an electromechanical valve apparatus having an armature operatively connected to the valve, a valve closing electromagnet capable of exhibiting an electromagnetic force for attracting said armature to close the valve, a valve opening spring for biasing said armature in a direction to open the valve, and a valve closing spring for biasing the valve closed, comprising:
instructions to de-energize the valve closing electromagnet; and
instructions to energize the valve closing electromagnet at a predetermined time after said de-energizing instructions, wherein said predetermined time is based on an integral number of valve periods, said valve period is the time elapsed between de-energizing the valve closing electromagnet until the valve returns to a nearly closed position for a first time when the valve closing electromagnet is maintained de-energized.

[c28] 28. The computer readable storage medium of claim 27 wherein the valve is an intake

valve, further comprising:
instructions to determine a desired amount of air to induct into said cylinder; and
instructions to determine said integral number of valve periods to cause said desired amount of air to be inducted into said cylinder.

[c29] 29. The computer readable storage medium of claim 28, further comprising instructions to determine an initiation time to de-energize the valve closing electromagnet to provide said desired amount air to said cylinder, said initiation time is based on a position of a piston disposed in the cylinder.

[c30] 30. The computer readable storage medium of claim 27, further comprising:
instructions to determine a desired amount of air to induct into the cylinder;
instructions to determine a desired amount of burned gases to trap in said cylinder;
instructions to determine said integral number of valve periods during which the valve is allowed to oscillate and to determine an initiation time to de-energize the valve closing electromagnet based on said desired amount of air and said desired amount of burned gases, said initiation time is based on a position of a piston disposed in the cylinder.

[c31] 31. The computer readable storage medium of claim 27, further comprising:
instructions to determine a desired amount of air to induct into the cylinder;
instructions to determine a desired turbulence level of the gases trapped in the combustion chamber; and
instructions to determine said integral number of valve periods during which the valve is allowed to oscillate and to determine an initiation time to de-energize the valve closing electromagnet based on said desired amount of air and said desired turbulence level, said initiation time is based on a position of a piston disposed in the cylinder.

[c32] 32. The computer readable storage medium of claim 27 wherein said integral number of valve periods is less than a predetermined number of valve periods.